Year: 2017

An anatomical study of plate-rod fixation in feline tibiae

Gutbrod, Andreas ; Vincenti, Simona ; Kühn, Karolin ; Knell, Sebastian Christoph ; Schmierer, Philipp A ; Pozzi, Antonio

Abstract: OBJECTIVE: To investigate the feasibility of placing bi-cortical cortex (B-cort) or mono-cortical locking screws (M-lock) in a plate-rod construct applied to the feline tibia in combination with different intramedullary (IM) pins. METHODS: Twenty-four feline tibiae of cats were divided into 4 groups, corresponding to IM pin sizes filling approximately 30% (1.0 mm), 40% (1.4 mm), 45% (1.6 mm), and 50% (1.8 mm) of the medullary canal. Computed tomography (CT) was performed to trace potential screw trajectories in each group. A 12-hole, 2.4 mm locking compression plate was then applied on the medial aspect of the tibia. M-lock and B-cort screws were inserted subsequently in each plate hole. Success rates of screw insertion based on CT analysis and cadaveric simulation were compared with screw type, IM pin diameter, and anatomic location as variables. RESULTS: Screw insertion rates were underestimated on CT compared to cadaveric specimens. During cadaveric simulation, B-cort screws could be inserted in all specimens in the 3 most proximal plate holes and in at least 1 of the 3 distal plate holes. The smallest pin size (30%) allowed placement of a greater number of B-cort screws ($P < .05$) compared to other pins. Fewer B-cort screws could be inserted in the distal diaphyseal region ($P < .05$) compared to other regions. A total of 99.3% of M-lock screws could be inserted regardless of IMP size. CLINICAL SIGNIFICANCE: Plate rod constructs can include bicortical screws in the proximal and distal metaphysis, and monocortical screws in the diaphysis, combined with an IM pin filling up to 50% of the medullary canal.

DOI: https://doi.org/10.1111/vsu.12678

Originally published at:
Gutbrod, Andreas; Vincenti, Simona; Kühn, Karolin; Knell, Sebastian Christoph; Schmierer, Philipp A; Pozzi, Antonio (2017). An anatomical study of plate-rod fixation in feline tibiae. Veterinary Surgery, 46(7):909-914.
DOI: https://doi.org/10.1111/vsu.12678

Title Page

Article Title: An anatomical study of plate-rod fixation in feline tibiae

Author Names:

Andreas Gutbrod[1], Dr. med. vet., DECVS, Simona Vincenti[1], Dr. med. vet., Karolin Kühn[2], Dr. med. vet., DECVDI, Sebastian Christoph Knell[1], Dr. med. vet., DECVS, Philipp Alexander Schmierer[1], DECVS, Antonio Pozzi[1] Prof. med. vet., DECVS

[1] Department for Small Animal Surgery, Vetsuisse Faculty, University of Zurich, Zurich, Switzerland

[2] Department for Diagnostic Imaging, Vetsuisse Faculty, University of Zurich, Zurich, Switzerland

This study has been presented as a short abstract at the 25th Annual Scientific Meeting of the ECVS July 7-9th 2016 in Lisbon, Portugal and at the ACVS Surgery Summit Oct 6-8th 2016 in Seattle, WA, USA.

No financial support was received and none of the authors have a conflict of interest.

Corresponding author:

Andreas Gutbrod

Winterthurerstrasse 260

CH-8057 Zürich

Switzerland

agutbrod@vetclinics.uzh.ch

An anatomical study of plate-rod fixation in feline tibiae

Objective: To investigate the feasibility of placing bi-cortical cortex (B-cort) or mono-cortical locking screws (M-lock) in a plate-rod construct applied to the feline tibia in combination with different intramedullary (IM) pins.

Methods: Twenty-four feline tibiae of cats were divided into 4 groups, corresponding to IM pin sizes filling approximately 30% (1.0mm), 40% (1.4mm), 45% (1.6mm) and 50% (1.8mm) of the medullary canal. Computed tomography (CT) was performed to trace potential screw trajectories in each group. A12 hole, 2.4 mm LCP was then applied on the medial aspect of the tibia. M-lock and B-cort screws were inserted subsequently in each plate hole. Success rates of screw insertion based on CT analysis and cadaveric simulation were compared with screw type, IM pin diameter, and anatomic location as variables.

Results: Screw insertion rates were underestimated on CT compared to cadaveric specimens. During cadaveric simulation, B-cort screws could be inserted in all specimens in the 3 most proximal plate holes and in at least 1 of the 3 distal plate holes. The smallest pin size (30%) allowed placement of a greater number of B-cort screws ($p<0.05$) compared to other pins. Fewer B-cort screws could be inserted in the distal diaphyseal region ($p<0.05$) compared to other regions. 99.3 % of M-lock screws could be inserted regardless of IMP size.

Clinical Significance: Plate rod constructs can include bicortical screws in the proximal and distal metaphysis, and monocortical screws in the diaphysis, combined with an IM pin filling up to 50% of the medullary canal.

Introduction

Comminuted fractures of long bones are common in cats, with a reported incidence of 58%.[1] Treatment options for comminuted fractures of the tibia in cats include external fixation, bone plating and placement of interlocking nails. In addition, combined fixation with a bone plate and intramedullary (IM) pin (plate-rod) construct has been advocated for bridging comminuted fractures.[2,3] Plate-rod constructs provide greater stiffness in bending and axial compression compared with bone plates [4,5] and significantly increase the fatigue life of the construct.[6] Plate-rod constructs also result in greater initial stiffness in compression and torsion compared to conventional interlocking nails,. [7] Another advantage of plate-rod constructs is that the IM pin facilitates fracture reduction and alignment.[2,8,9] Application of plate-rod is feasible in most cases, although the interference between IM pin and screws may prevent bicortical screw fixation in some locations. This problem is especially relevant in feline tibial fractures due to the small diameter of the medullary canal. Monocortical screws may be utilized to avert this problem, although at least one bicortical screw should be placed in each bone fragment to optimize torsional stability.[5,10-12] However, no research has focused on determining the best screw combination for plate-rod fixation of the feline tibia.

The purpose of this study was to investigate the feasibility of placing bi-cortical cortex (B-cort) or mono-cortical locking screws (M-lock) in a 12-hole, 2.4 mm locking compression plate (LCP) applied to the medial aspect of a feline tibia, in combination with IM pins of increasing diameter, approximating 30%, 40%, 45% and 50% of the medullary canal diameter. We hypothesized that in both computed tomographic (CT) and cadaveric simulations of a plate-rod construct in a feline tibia1) decreasing the diameter would IM pins would increase the number of B-cort screws inserted into the tibia; 2) a greater number of B-cort screws could be inserted into the proximal tibial metaphysis compared to the diaphysis and the distal metaphysis, regardless of IM pin size, and 3) M-lock screws could be inserted in any location, regardless of IM pin size.

Materials and Methods

Specimen Preparation

24 unpaired tibiae were collected from adult cats euthanized for reasons unrelated to this study. The soft tissues were removed and orthogonal radiographs of the isolated tibiae were obtained. The internal medullary canal diameter was measured at the isthmus of the diaphysis on mediolateral projections. Tibial length was measured from the distal aspect of the medial malleolus to the intercondylar eminence. Specimens were excluded if the conformation of the tibia was abnormal, pathology was detected, or if the internal medullary canal diameter was less than 3.4 mm or greater than 3.6 mm at the isthmus. This restriction was designed to standardize specimen' size and ensure consistent canal fill with a specific IM pin diameter throughout the study. The tibiae were wrapped in towels soaked in 0.9% NaCl solution and stored at -20°C until 24 hours prior to testing, at which time they were thawed to room temperature. The bones were randomly assigned to four groups. We used a block randomization and grouped the absolute intramedullary diameters into 3.3, 3.4, 3.5, and 3.6 mm. A Kirschner wire was selected to approximate 30%, 40%, 45% and 50% filling of the medullary canal. The Kirschner wire was 1.0 mm diameter for group A ('30%'), 1.4 mm diameter for group B ('40%'), 1.6 mm diameter for group C ('45%'), and 1.8 mm diameter for group D ('50%') IM pins.

The following steps were taken sequentially for each tibia: 1) implantation of an IM pin, 2) application of plastic replica and CT scan to trace the potential screw trajectory, detect

Dominique Griffon 4/4/2017 10:58
Kommentar [1]: Is this OK?

possible screw-IM pin impingement and evaluate feasibility of screw insertion, and 3) application of a 2.4 mm LCP to the medial surface to determine the feasibility of screw insertion in the cadaver specimen. The IM pin was inserted in a normograde fashion, with the insertion point medial to the patellar ligament and cranial to the intermeniscal ligament[13] and was advanced until firmly seated in the cancellous bone of the distal metaphysis.[3]

Computed tomographic simulation

The placement of screws through the plate holes of a 2.4 mm LCP was simulated with a custom-made, contoured, 3D printed plastic replica (CM-Design AG, Adliswil, Switzerland) of a 12-hole 2.4 mm LCP (Depuy Synthes Vet, West Chester, PA), designed to reduce artifact associated with metallic implants. A model was created from the scan of an original 12 hole 2.4 mm LCP, and the flexible replica was fabricated with a PLA filament 3D printer. The replica was secured with tape to the medial aspect of each tibia in all groups, simulating a well-contoured plate. The plate holes were sequentially numbered 1-12 from proximal to distal. The space between the 6th and 7th hole of the plate replica was positioned over the center of the tibia. The position of the plate was marked on the tibia using a 1.5mm drill bit to create a small cortical defect in the bone at the level of the first and 12th plate hole to permit detection of any accidental movement. Computed tomography (CT) of the entire tibia, IM pin and plate was obtained on each specimen using multi-detector-CT (Brilliance CT 16, Philips AG, Zürich, Switzerland). The CT studies were acquired with a standard protocol for orthopedic cases with images obtained through the short axis of tibia and implant in order to reduce metallic artefacts. Scanning parameters were: 120 kVp, 250 mA, pitch 0.688, rotation time 0.75 s, detector collimation of 16 x 0.75). Raw data was reconstructed in a high spatial frequency algorithm in a slice thickness of 0.5 mm. The images were exported to a workstation (OsiriX Imaging Software v.4.1. 64-bit, Geneva, Switzerland;) and reviewed in a window optimized for metallic implants (WL: 600/ WW: 5000). The images were reconstructed to create transverse sections of the tibia perpendicular to the LCP at the level of each plate hole.

The trajectories of B-cort and M-lock screws were traced to detect screw-IM pin impingement on each transverse CT image,. The potential corridors for B-cort and M-lock screws were defined based on screw outer diameter and the insertion angle of these screws relative to the 2.4 mm LCP. To predict if a B-cort screw could be inserted, a line was drawn starting at the plate hole tangential to the IM pin at either the cranial or caudal edge. The angle between this line and the surface of the plate replica was calculated and defined as the insertion angle. A second line was then drawn parallel to the first one at a distance equal to the outer diameter of the screw, marking the insertion corridor (Fig. 1A). The criteria for successful B-cort screw insertion were 1) the insertion corridor was within the medullary canal; 2) the insertion angle was not greater than the recommended angle of 7° for the 2.4 mm LCP.

The insertion corridors of M-lock screws were drawn using a similar method, but at a fixed 90° insertion angle relative to the plate (Fig. 1B). The criteria to define if a M-lock screw could be inserted was the ability to extend the outline of the locking screw 2 mm into the medullary canal without interference with the IM pin. This would correspond to a monocortical screw fully placed in the cis-cortex. CT simulation was also used to determine if the B-cort should be inserted cranially or caudally to the IM pin in the cadaveric specimen. Measurements were performed by three investigators (SV, KK, AG), a surgical resident, a board certified radiologist, and a board certified surgeon. The mean values were used for statistical analysis. Mean values for insertion angles were used as guideline to perform the cadaveric simulation.

Cadaveric simulation

After completing the CT scans, the plastic replica was removed and exchanged for a contoured stainless steel 12-hole 2.4 mm LCP (Depuy Synthes Vet, West Chester, PA) matching the marking from the plastic replica to ensure similar placement. The plate was applied first with all 2.4 mm locking screws, followed by 2.4 mm cortex screws. The 1.8 mm locking drill guide was inserted into the combi-hole and a 1.8 mm diameter hole was drilled through the cis-cortex. A 6 mm long 2.4 mm self-tapping, locking screw was inserted into each plate hole. If the head of the screw could not be fully inserted into the LCP plate, the number of the screw hole was recorded and considered as not suitable for M-lock screw placement.

After removing the M-lock screws, the B-cort screws were inserted. A 1.8 mm drill bit was directed cranially or caudally based on the findings of the CT scan. A 22 mm long 2.4 mm self-tapping screw was then inserted into each screw hole, beginning with the most proximal and the most distal plate holes. The remaining plate holes were filled from proximal to distal. All screws were placed and hand-tightened by an experienced board-certified surgeon (AG) in accordance with the standard technique.[14]

The tibiae were progressively osteotomized in multiple transverse planes proximal to each screw after removal of the IM pin, in order to evaluate B-cort screws for correct bicortical placement. The screws were visualized by looking from proximal to distal within the medullary cavity. Each screw was assessed for true bicortical engagement and was then removed to allow evaluation of the next distally placed screw. A screw was considered bicortical if the entire diameter of the screw was within the medullary cavity at least at a single point. In borderline cases, a 0.6 mm diameter orthopedic wire was used to palpate the presence of a gap between the inner cortex and the screw. B-cort screw placement was considered not possible if the screw could not be fully inserted in the trans-cortex, for instance due to interference with the IM pin. The number of the affected plate hole was recorded.

Data and statistical analysis

The outcome measures of the study were: 1) the overall successful insertion rates of B-cort and M-lock screws with IM pins of increasing medullary fill based on CT scan and cadaveric simulation, and 2) the successful insertion rates of B-cort and M-lock screws in each anatomical region of the tibia with IM pins of increasing medullary fill.

The overall successful insertion rate was calculated as the number of screws that could be inserted relative to the absolute number of plate holes. To evaluate the effect of anatomical region of the tibia on insertion rate, the insertion rates for 3 adjacent plate holes were pooled, yielding a pooled insertion rate for the proximal metaphysis (PM), proximal diaphysis (PD), distal diaphysis (DD), and distal metaphysis (DM). The following comparisons were performed using Chi-Square analysis (GraphPad Prism 7, version 7.0a, GraphPad Software, San Diego, CA, USA):

1) Overall insertion rates of B-cort and M-lock screws based on CT and cadaveric simulations;
2) Insertion rates of B-cort and M-lock screws among groups A, B, C and D in cadaveric simulation;

3) Insertion rates of B-cort and M-lock screws among anatomical regions PM, PD, DD and DM on cadaveric simulation.

For all statistical analyses performed, $p < 0.05$ was considered significant.

Results

Based on radiographic measurements, 1.0, 1.4, 1.6 and 1.8 mm diameter K-wires were calculated to occupy 29.0% ± 0.8%, 40.6% ±0.9%, 46.4% ± 1.0% and 52.2% ± 1.5% of the internal diameter of the medullary canal at the isthmus of the tibial diaphysis, respectively. Tibial length did not differ between groups (p=0.412) with a mean of 11.9 ± 0.71 cm. CT scan measurements underestimated the cadaveric insertion rates of both B-cort and M-lock screws (p<0.05) (Fig. 2). On cadaveric simulation, fewer bicortical screws could be inserted in groups B, C and D when compared to group A (p<0.05) (Fig. 3), however, there was no difference in B-cort screw insertion rate among groups B, C or D. In all groups, all screws could be successfully inserted in the plate holes numbered 1, 2 and 3. A B-cort screw could be placed into hole number 12 in 22/24 times (92%). The overall insertion rate for M-lock screws was 99.3 % and no difference was found regarding IM pin diameter (p=0.1096) or anatomic location (p=0.1456).

When pooled together, all B-cort screws could be successfully inserted in the PM region (100%, 72/72), followed by the PD and DM region (81.9% 59/72 each), and with the least amount of screws inserted in the DD region (36.1 % 26/72, Table 1). When the insertion rate was compared among the anatomical regions PD, DD and DM for each IM pin group, significantly more screws could be inserted in group A in these regions compared with B, C, and D (p<0.05) except for region PD and DM in group A versus group C (p=0.15 and p=0.07).

Discussion

This study investigated the feasibility of placing 2.4 mm monocortical locking or bicortical cortex screws in a plate-rod construct applied to tibiae of cats in conjunction with IM pins of increasing diameter. In agreement with our hypotheses, an overall greater number of B-cort screws could be inserted after placement of an IM of smaller diameter. B-cort screws could always be placed successfully in the proximal metaphysis, regardless of the size of IM pin, and in most specimens, in the most distal hole in the distal metaphysis. In contrast, M-lock screws could be successfully inserted in all regions of the tibia. Based on our results, it appears that plate-rod constructs with a 2.4 mm LCP combined with an IM pin of 40%, 45% or 50% medullary diameter would require a combination of bicortical and monocortical screws.

Based on our results, we suggest that plate-rod constructs in cats with diaphyseal fractures include a plate that extends to the most proximal and distal regions of the bone to allow placement of at least one bicortical screw per fragment. Indeed, bicortical screws could be placed in all of the five most proximal plate holes and in the most distal hole in 97.5% and 92% of the times, respectively, regardless of the IM pin size. This finding is expected because the larger diameter of the metaphysis, especially in the proximal tibia, allows the surgeon to direct the screw in the opposite direction of the IM pin. Based on our findings, the screws may be directed cranially or caudally in the proximal and distal regions of the tibia, respectively. We would not recommend attempting to place bicortical screws in the distal diaphysis of the tibia because insertion was possible only in about 50% of the attempts. Although we did not record the effect, placement of a bicortical screw should not be attempted in the diaphyseal area, because even if the drill bit might pass the IM pin, the diameter of the screw will often be too large, creating a 1.8 mm empty drill hole on the trans-cortex, thereby affecting the mechanical properties of the bone.[15,16]

By contrast, mono-cortical screws could be placed in 99.3 % of the cases and, as anticipated, was not reliant on IM pin diameter. Mono-cortical screws have been found mechanically acceptable in a bone model using locking plates, if combined with at least one bicortical screw in each fracture segment. The bicortical screws would ideally be placed close the fracture line, with the distant placement considered the second best configuration for torsional stiffness.[12] Our results show that bicortical screw placement close to a diaphyseal fracture site is not feasible in plate-rod constructs in feline tibiae due to the narrow medullary canal in the mid-diaphysis, and likely interference with the IM pin. The optimal location of bicortical screw placement relative to the fracture in cats is unknown; however, bicortical screw could reliably be placed at the proximal and distal extents of the bone, distant to the fracture line, in this study.

Our results support the use of 1.4, 1.6 or 1.8 mm IM pins in feline tibiae with internal medullary canal diameters measuring 3.4 - 3.6 mm at the isthmus, when combined with long bone plates accommodating locking and non-locking screws. The IM pin diameter can therefore be selected based on the mechanical requirements of the fracture, rather than being dictated by the anatomical features of the feline tibia. Although not investigated, we assume that these results can be extrapolated to a wider range of intramedullary canals, as long as the diameter of the IM pin is selected to fill 40%, 45%, or 50% of the medullary canal. The Influence of pin diameter on plate rod constructs has been extensively studied in canine femora[5-7,17] and tibia.[4,18] Authors of these studies concluded that the IMP diameter should approximate 35 - 40 % of the medullary cavity, and that for each 10% increase in canal fill,

Dominique Griffon 4/4/2017 11:56

Kommentar [2]: Is this what you intended to say? This seems to contradict your statement line 275 – Feel free to clarify /edit plate strain was reduced by about 20%.[6] Larger relative diameters were considered to result in a construct that was too rigid to promote bone healing. Clinical guidelines regarding the ideal IM pin diameter for plate-rod constructs in tibiae of cats cannot be extrapolated based on our study, because several factors such as plate size and fracture configuration play a role in IM pin selection and the required amount of stability for fracture healing in the feline tibia is unknown. In addition, clinical application of a LCP should strictly follow AO principles: cortical screws should be placed before locking screws, and a plate-screw density of less than 0.5 should be achieved. Although we could have used a smaller implant, we selected the upper limit of clinically used plate rod implants in cats. The 2.4 mm LCP was selected to simulate a challenging situation, where relatively large screws would be combined with an IM pin. Future mechanical and clinical studies are needed to define guidelines for plate-rod constructs in cats.

Dominique Griffon 4/4/2017 11:59
Kommentar [3]: This seems to contradict your statement above

The CT simulation underestimated the percentage of screws that could be inserted compared with the cadaveric simulation. One possible explanation is that the screw corridors traced on the CT images could not take into account deviation of the IM pin secondary to screw insertion. Screws were placed from proximal to distal and the inserted screw might have shifted the IM pin rendering the CT measurements for the next distal plate hole invalid. In addition, the CT simulation overestimated the diameter of the IM pin due to metal-related artifact. Such artefact could have been prevented by using a plastic replica for the IM pin, similarly to the replica used for the plate. However, it may not have been possible to exchange this replica after CT, with a stainless steel pin positioned in the exact same location before cadaveric simulation, creating variation between assessment methods. Another limitation of our study is that we did not evaluate bi-cortical locking screws. We chose to test M-lock because previous studies have suggested that a plate-rod construct with M-Lock may

Dominique Griffon 4/4/2017 11:55
Kommentar [4]: Is this what you intended to say? If not, edit and clarify as your original statement was confusing

provide sufficient stability for clinical use, especially including B-cort screws in the metaphyseal area.[12] Being an *ex-vivo* study, the results of the cadaveric simulation may also be limited by the reduced elasticity of cadaveric bones.

Based on our findings, we recommend plate rod fixation of feline tibiae with a 12 hole 2.4 mm LCP plate including bicortical screws in the most proximal and distal plate holes. Additional bicortical screws can be inserted in the proximal metaphyseal region, aiming in a cranial direction regardless of IM pin size. In the distal half of the tibia, bicortical screw placement should be attempted only if an IM pin with 30% filling of the medullary canal is used, except for the most distal plate hole where screws should be directed caudally. Monocortical locking screws can be safely placed regardless of location or IM pin diameter.

References:

1. Nolte DM, Fusco JV, Peterson ME. Incidence of and predisposing factors for nonunion of fractures involving the appendicular skeleton in cats: 18 cases (1998-2002). *J Am Vet Med Assoc* 2005;226:77–82

2. Johnston SA, von Pfeil DJF, Déjardin LM, et al: Internal Fracture Fixation, in: Tobias KM, Johnston SA (eds): *Veterinary surgery small animal*, St. Louis, MO, Saunders, 2012, p 576

3. Reems MR, Beale BS, Hulse DA. Use of a plate-rod construct and principles of biological osteosynthesis for repair of diaphyseal fractures in dogs and cats: 47 cases (1994-2001). *J Am Vet Med Assoc* 2003;223:330–335

4. Glyde M, Day R, Deane B, et al: Biomechanical comparison of plate, plate-rod and orthogonal plate locking constructs in an ex-vivo canine tibial fracture gap model. *ECVS 20th Annual Scientific Meeting* 2011;p88

5. Hulse D, Hyman W, Nori M, et al: Reduction in plate strain by addition of an intramedullary pin *Vet Surg* 1997;26:451–9

6. Hulse D, Ferry K, Fawcett A, et al: Effect of intramedullary pin size on reducing bone plate strain. *Vet Comp Orthop Traumatol* 2000;13:185–90

7. von Pfeil DJ, Déjardin LM, Decamp CE, et al: In vitro biomechanical comparison of a plate-rod combination–construct and an interlocking nail–construct for experimentally induced gap fractures in canine tibiae. *Am J Vet Res* 2005;66:1536–43.

8. Johnson AL, Houlton JEF, Vannini R: *AO principles of fracture management in the dog and cat*. Zurich, Switzerland, AO Publishing, 2005, p546

9. Hudson CC, Pozzi A, Lewis DD. Minimally invasive plate osteosynthesis: applications and techniques in dogs and cats. *Vet Comp Orthop Traumatol* 2009;22:175-182

10. Gautier E, Sommer C: Guidelines for the clinical application of the LCP. *Injury* 2003;34:63–76

11. Demner D, Garcia TC, Serdy MG, et al: Biomechanical comparison of mono- and bicortical screws in an experimentally induced gap fracture. *Vet Comp Orthop Traumatol* 2014;27:422–9

12. Demianiuk RM, Benamou J, Rutherford S, et al: Effect of Screw Type and Distribution on the Torsional Stability of 3.5 mm String of Pearls Locking Plate Constructs. *Vet Surg* 2014;44:119-125

13. Kowaleski M, Boudrieau RJ, Pozzi A: Stifle Joint, in: Tobias KM, Johnston SA (eds): *Veterinary surgery small animal*, St. Louis, MO, Saunders, 2012,pp. 906–98

14. Koch D: Screws and plates, in: Johnson AL, Houlton JEF, Vannini R (eds) *AO Principles of Fracture Management in the Dog and Cat*. Zurich, Switzerland, AO Publishing, 2005, pp27–51.

15. Edgerton BC, An KN, Morrey BF. Torsional strength reduction due to cortical defects in bone. *J Orthop Res* 1990;8:851-855

16. Brooks DB, Burstein AH, Frankel VH. The biomechanics of torsional fractures.

The stress concentration effect of a drill hole. *J Bone Joint Surg Am* 1970;52:507–14

17. Goh C, Santoni B, Puttlitz C, et al: Comparison of the mechanical behaviors of semicontoured, locking plate-rod fixation and anatomically contoured, conventional plate-rod fixation applied to experimentally induced gap fractures in canine femora. *Am J Vet Res* 2009;70:23–9

18. Beierer LH, Glyde M, Day RE, et al: Biomechanical comparison of a locking compression plate combined with an intramedullary pin or a polyetheretherketone rod in a cadaveric canine tibia gap model. *Vet Surg* 2014;43:1032–8